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# In situ measurement of atomic oxygen flux using a silver film sensor onboard "TianTuo 1" nanosatellite

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**Abstract**

Research into the measurement of atomic oxygen (AO) flux in a low Earth orbit (LEO) is highly significant for the development of spacecraft surface materials as well as for enhancing the reliability of space instruments. In the present study, we studied a silver film resistance method for AO flux measurement and we established a quantitative calculation model. Moreover, we designed a silver film sensor for space flight tests with a mass of about 100 g and a peak power consumption of less than 0.2 W. The effect of AO on the silver film was demonstrated in a ground-based simulation experiment and compared with the Kapton-mass-loss method. For the space flight test, the AO flux was estimated by monitoring the change in the resistance in the linear part of the silver/AO reaction regime. Finally, the sensor was carried onboard our nanosatellite "TianTuo 1" to obtain in situ measurements of the AO flux during a 476 km sun synchronous orbit. The result was critically compared with theoretical predictions, which validated the design of this sensor.


*Keywords:* Atomic oxygen; Calculation model; Flux; Silver film; Space flight test

## 1. Introduction

The environment in space is one of the main causes of spacecraft abnormalities and failures. Atomic oxygen (AO) is the major and most active component of the low Earth orbit (LEO) neutral atmosphere, where it accounts for almost 80% of the atmospheric composition (Sliverman, 1995). AO can have severe effects on LEO spacecraft. In particular, AO can react directly with materials due to its strong oxidizability. In addition, AO has an impact energy of 4–5 eV on the outer surface of spacecraft at a high relative velocity, even without considering thermal movement. High-speed collisions may cause severe erosion and degradation of spacecraft materials, such as polymers, composite materials, thermal control coatings, metal wires, and solar cells, thereby affecting their chemical, electrical, thermal, optical, or mechanical properties (Samwel, 2014). All of these factors may jeopardize the on-orbit safety of spacecraft and the capacity to accomplish their missions. Therefore, studying the effects of AO is very important for ensuring the high reliability and longevity of spacecraft, and thus it is necessary to monitor the AO flux in the LEO space environment.

AO flux is defined as the number of AO atoms that pass through a unit area within unit time, which is given as atoms/$m^2$ s. Numerous ground-based experiments and LEO flight experiments have been performed, so large volumes of data are available for AO flux estimation and research into the effects of AO. Many of these experiments were conducted during short duration shuttle missions, including STS-5, STS-8, STS-41G, and STS-46 (Visentine, 1989; Shen et al., 2006). Consequently, several methods have been established for AO flux measurement,

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including the Kapton-mass loss method, $NO_2$ titration method, silver surface catalysis method, emission spectrum method, mass spectrum method, silver film resistance method, and the semiconductor sensor method (Bennett and Omidvar, 2001; Yoshimura et al., 2003; Kaspar et al., 2010). Compared with ground-based experiments, space flight tests have higher credibility and value because they can obtain first-hand data, which makes them more desirable. However, the test results obtained from most space flights rely on the analysis of retrieved material samples and expensive complex equipment, but the current trend for using micro- or even nanosatellites in scientific missions means that AO flux measurements can be acquired onboard small satellites if the mass, power budget, and size of the AO sensor can be kept within reasonable limits. Resistance-type sensors can be employed in active, online techniques for the real-time measurement of AO flux or fluence (time cumulative flux) by monitoring the change in resistance, thereby providing significant mass/power benefits in terms of engineering compared with other techniques. Suitable AO sensing materials include silver, carbon, osmium, and zinc oxide (Osborne et al., 2001; Carl et al., 2005). Silver film sensors have a high erosion yield, short sampling period, and fast response (Harris, 1997; Harris et al., 1997a), which makes them suitable for short-duration flight tests, as performed in the present study. A patent application has been filed at the China Patent Office for the sensor described in this study.

During the early 1970s, a silver film resistance sensor was first employed to investigate the lower thermosphere on sounding rockets. This technique has been applied during on-orbit tests in two previous studies (retrievable and nonretrievable orbital spacecraft) (Harris, 1997; Osborne et al., 2001), but the instruments differed in several respects compared with that developed in the present study. This was the first AO erosion experiment to be conducted by a nanosatellite mission on LEO orbit and very few in situ measurement experiments have been performed in China. We used relatively thick uncoated silver films, whereas previous experiments only monitored coated sensors or they employed very thin films. Our instrument also underwent ground testing based on comparisons with the Kapton film mass loss method, which were not conducted in most previous studies. Moreover, a quantitative calculation model was established for the AO flux, where we focused on analyzing the silver film to measure the AO flux in this study. In particular, we mainly considered the average AO flux measurements, which may be more useful for understanding the effect of AO on spacecraft. By contrast, atmospheric scientists have focused on building more accurate models of the AO concentration as functions of the date, time, latitude, longitude, and altitude (Picone et al., 2002).

This remainder of this paper is organized as follows. In Section 2, we outline the principle and composition of the silver film sensor. In Section 3, we derive in situ resistance measurements of the silver film and establish a model for calculating the AO flux with this sensor. In Section 4, we present the results of ground-based simulation experiments, which we performed to validate the effect of AO on the silver film. We also provide details of the space flight test. We present the results and discuss these two experiments in Section 4. We give our conclusions in Section 5.

## 2. Sensor construction

The proposed instrument based on silver film erosion for AO flux measurement is essentially a resistance-type sensor. The principle of this sensor is as follows (Harris et al., 1998; Gabriel et al., 1998). When exposed to an AO environment, the silver film reacts to form electrically non-conducting oxides. The unstable silver oxide layer flakes off due to fatigue in the on-orbit conditions, e.g., thermal cycling and vibration. The fresh silver is then exposed to AO and the reaction continues. Consequently, the thickness of the silver film will decrease constantly and thus the resistance value will increase gradually. The course of this reaction can be monitored remotely by measuring the film's resistance and these measurements can then be used to estimate the AO flux by considering other factors, such as contact resistance, incident angle, temperature, and exposure time.

A schematic diagram of the AO sensor is shown in Fig. 1. The AO sensor comprises two parts: the detector unit and measurement unit. In the tests, the detector unit was mounted on the windward side of the “TianTuo 1” to react chemically with AO, where it had to withstand the acceleration and vibration of the launch phase, and subsequently it operated in the characteristic thermal, vacuum, and radiation environment of space (Harris et al., 1997b). We manufactured the sensor by laser sputtering and sintering pure silver onto the substrate, thereby depositing a silver film layer on the surface. The substrate selected for the detector unit was an alumina ceramic due to its good insulation performance, very low linear expansibility, high breakdown strength, high mechanical strength, and chemical inertness. The silver film was configured in thin grid strips to achieve a balance between high resistance and limited size. The measurement unit inside

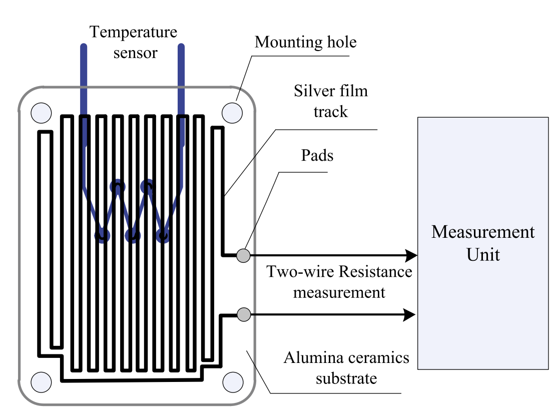


Fig. 1. Schematic diagram of the AO sensor.